Factors Influencing the Regeneration of Eastern Hemlock (*Tsuga Canadensis*) at UNDERC East

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Abstract

The decline of the eastern hemlock has been studied in the Upper Great Lakes region for decades. Numerous factors, including heavy browse by overpopulated deer, as well as global temperature increase, have made hemlock stands more susceptible to encroachment by competitor hardwoods like sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and balsam fir (*Abies balsamea*). By counting juvenile hemlocks in several pure and mixed stands at the University of Notre Dame Research Center, we hoped to gain an understanding of the regeneration quality in these stands. Our study examined several abiotic factors hypothesized to influence hemlock regeneration, including leaf litter composition, leaf litter depth, light availability, and soil moisture, to see if certain conditions were more favorable to hemlock establishment. Overstory composition obtained from adult tree surveys was then compared to the understory composition in terms of tree species proportion. No significant relationships were observed between number of hemlock seedlings and saplings and any of the abiotic factors. Hemlocks were also not observed to be statistically more likely to be browsed vs unbrowsed, or growing on coarse woody debris vs forest floor. However, there was a significant difference in the proportion of hemlocks in the understory vs overstory, suggesting that hemlock are not regenerating at rate that will ensure their continued presence in the forests of the upper great lakes region.

Introduction

Northern hemlock (*Tsuga canadensis*) is a highly shade-tolerant coniferous tree native to hardwood forests in the northeastern United States (Godman and Lancaster 1990). The dense canopy of hemlock stands creates a cool, moist microclimate which supports unique herbaceous plant and shrub communities (Quimby 2001). These stands are utilized for food and shelter by terrestrial wildlife including white tailed deer (Witt and Webster 2010; Kreuger and Peterson 2006; Thurston, L., & Euler 1980; Frelich and Lorimer 1985; Mladenen and Stearns 1992), ruffed grouse, turkey, snowshoe hare, black bear (Carey, 1993), and numerous species of birds. (Quimby 2001). Dense hemlock canopies also influence aquatic communities; aquatic invertebrate diversity and brook trout abundance tend to be higher in streams shaded by hemlock due to the cooling effect (Evans et. all, 1995). Hemlock is successful in late-successional systems due to its extreme longevity and tolerance to shade (Hugh, 1987)

Historically, forests of the upper peninsula of Michigan were dominated by hemlock, sugar maple, spruce, and beech. Clear-cut logging practices in the mid 1800's transformed the North

Woods landscape from old growth to early-successional status (Woods 2000; Rhemtulla et. all 2009). Subsequent regrowth has produced the second-growth forests that exist across much of Wisconsin and Michigan today. Modern forests have a much greater proportion of deciduous hardwood trees, a shift in species composition that has been detrimental to eastern hemlock, which is typically outcompeted by deciduous species in second-growth systems (Davis 1993). As a result, hemlock stands in second growth forests are vulnerable to encroachment by competitor species. The persistence of hemlock within the ecosystem is dependent on the ability of these stands to successfully regenerate and maintain their hold on the landscape (Hett and Loucks 1976).

Due to the importance of eastern hemlock in Northwoods ecosystems, determining the regeneration capabilities of stands on the UNDERC property is critical. Regeneration is determined primarily by stand demographics; the number of seedlings and saplings present reflect the capacity of the stand to replace lost adult trees (McWilliams et al., 2011). This regeneration can be influenced by a number of factors including soil moisture, availably of light, proportion of competitor saplings browse by deer, depth and composition of leaf litter, and presence of coarse woody debris.

Hemlock seeds germinate poorly in soil which is not sufficiently moist, and hemlock seedlings and saplings are susceptible to desiccation due to their shallow root systems (Godman and Lancaster 1990; Quimby 2001). Moist conditions are perpetuated by the insulating canopy of older hemlocks, but when adult trees are removed via anthropogenic or natural disturbance, the site is released of the shade which helps the soil maintain its temperature and hold moisture (Evans et. all, 1995). Light availability is a critical variable because hemlock's shade tolerance gives it an advantage over competitor hardwoods under dense canopy cover. Canopy gaps created through tree mortality in mixed hardwood-hemlock stands could lead to higher rates of encroachment by species like sugar maple (*Acer saccharum)* and basswood (*Tilia americana*), which would have greater fitness under high light conditions. Finally, deciduous leaf litter can smother shorter saplings, or prevent the germination of hemlock seeds unable to access the moist soil (Kostal-Hughes et. all 2005).

Herbivorous browse can severely stunt the growth of seedlings and, eliminate them from the regeneration stock (Kreuger,and Peterson 2006). White-tailed deer have a strong preference for hemlock saplings when foraging in the winter, when they also use the dense hemlock canopy as cover from snowfall and wind (Frelich and Lorimer 1985). Coarse woody debris (CWD) can be a refuge from both deer browse and unfavorable soil conditions (Kotanen and O'Hanlon-Manners 2004). Additionally, decomposing wood generates the warm, moist environment which hemlock seeds require for germination, and therefore is a favorable substrate for hemlock growth.

We hypothesize that shallow, primarily coniferous leaf litter will be more conducive to hemlock regeneration. Moist soils, and lesser light availability should also result in a greater number of hemlock seedlings and saplings being present in a stand. We also expect that a greater number of hemlocks will be browsed than unbrowsed, and that more hemlocks will be present on coarse woody debris than the forest floor. Finally, we expect to see a significant contrast between overstory and understory composition at the hemlock stands surveyed, with a greater proportion of hemlocks in the canopy than can be replaced by the regeneration below.

Methods

We collected data from hemlock stands identified via a georeferenced GIS map of the UNDERC property. One to three plots were placed in each stand, with a minimum distance of 50m between plots. We set up 14-by-21 meter rectangular plots, each with a 7-by-7 meter grid of interior subplots (Rooney et. all, 2000). Within each subplot, all hemlock seedlings (height < .5m) and saplings (height > .5m) were counted. For each juvenile hemlock encountered, their growth substrate (forest floor vs coarse woody debris) and browse status (browsed vs unbrowsed) was recorded. Competitor seedlings and saplings were counted and recorded within three randomly selected subplots.

Abiotic factors measured included light availability, leaf litter composition, and leaf litter depth. Leaf litter composition was determined via percent cover within a .36m^2 quadrat. Percent cover, categorized into deciduous litter, coniferous litter, and other (sticks, grasses, moss, etc) was recorded. Leaf litter depth was then taken within the frame using a ruler. Light availability was measured using a densiometer, with measurements (percent open canopy) taken facing each cardinal direction. These values were averaged for analysis. To evaluate soil moisture, we collected soil samples and determined their mass in grams before and after drying. This difference was then used to calculate gravimetric soil moisture (g water/g soil). All abiotic measurements were taken within the same three randomly selected subplots within each plot.

All adult trees within the plot were surveyed examine the species composition in the stand overstory. Tree species, canopy class, and DBH were all recorded. Species identified within plots included eastern hemlock (*Tsuga canadensis*), white birch (*Betula papyrifera*), yellow birch (*Betula allegheniensis*), balsam fir (Abies balsamea), red cedar (*Thuja occidentalis*), red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), white pine (*Pinus strobus*), and American basswood (*Tilia Americana*). Canopy classes included dominant trees above the canopy, codominant trees within the canopy, intermediate trees slightly below the canopy, and suppressed trees far below the canopy.

Abiotic factors including light availability, leaf litter depth, and percent non-coniferous leaf litter were all normally distributed. The number of hemlock seedlings and saplings, as well as the gravimetric soil moisture, were not, so a natural log transformation was performed in order to conduct parametric statistical analyses. Hemlock regeneration, represented by the hemlock seedling and sapling count, was compared against these abiotic factors via linear regression. Substrate type and browse presence were non-normal and could not be made normal via transformation. Therefore, a Wilcox signed rank test was performed to compare these factors to juvenile hemlock abundance in place of a paired t-test. The proportion of hemlocks in the overstory and understory was compared by plot, also utilizing this nonparametric test.

Results

The relationship between light availability and number of hemlock seedlings/saplings was not statistically significant, with a p-value of .248. The relationship between leaf litter depth and number of hemlock seedlings/saplings was also not statistically significant, with a p-value of .93. Percent non-coniferous leaf litter also showed no statistical relationship with the number of hemlock seedlings and saplings present with a p-value of .875. Finally, gravimetric soil moisture, with $p=.217$, showed no significant relationship to the number of hemlock seedlings and saplings present (Figure 1).

A Wilcox signed rank test between substrate type and the number of hemlock seedlings and saplings present showed no significance, with a p-value of .753. Similarly, in a Wilcox signed rank test between number of hemlock seedlings and saplings and presence of browse, no significance was found with a p-value of $p=.222$. A linear regression comparing the number of competitor seedlings and saplings and the number of hemlock seedlings and saplings also showed no significant relationship, with a p value of .5003.

The proportion of hemlocks in the understory was significantly different than the number of hemlocks in the overstory (Fig. 4). A p-value of .0001 was obtained after performing a nonparametric Wilcox signed rank test due to non-normal data distribution.

Discussion

The lack of significant abiotic relationships observed in this study could be attributed to a small sample size. Light availability and soil moisture had smaller p-values when compared to other abiotic factors, which could mean that these factors would have been significant with a greater sample size. In a paper by Rooney et. all published in 2000, a significant correlation was found between hemlock seedling number and light availability, meaning that comparatively smaller size of my p-value for this factor may represent the potential for true ecological significance.

Initially, we had not considered balsam fir as being a serious competitor in hemlock-hardwood forests. After our study, it appears that this species may represent a threat to hemlocks due to similar life history characteristics. Balsam fir seedlings thrive in the moist soils perpetuated by hemlock stands, and are highly capable of growth even in very limited light conditions. In this way, balsam fir and hemlock are evenly matched under similar abiotic conditions. However, preferential browse of hemlock by deer may give balsam fir the advantage during spring growth (Rawinski, 2016).

No hemlock saplings were observed, likely due to seedlings being browsed to death before reaching heights greater than .5 meters. Rooney et all (2000) found that only hemlock saplings are significantly impacted by browse. This could be because hemlock are highly favored by deer during the winter. While seedlings are safely covered by snowpack, saplings with exposed stems will be heavily browsed, removing photosynthetic potential and decreasing the fitness of the juvenile (Mladenoff and Stearns, 1993).

The differences in overstory and understory compositions was strongly significant, showing a clear difference in the proportion of hemlocks present in the understory vs the overstory. The most prevalent overstory tree was typically hemlock, but this dominance was not observed in the understory, which was composed primarily of competitor species like maple and fir (Fig. 2, Fig. 3). Interestingly, white cedar was sometimes present in the overstory, but juveniles were never observed. Future studies should be done to assess the regeneration of this hydrophilic coniferous tree that often grows in association with eastern hemlock.

This study did not provide any significant evidence of connection between the number of hemlock seedlings and saplings present in an area and the local abiotic conditions. However, our research did show that the understory is not representative of the overstory in hemlock stands, suggesting that hemlock regeneration is poor. Since statistical analysis did not find any relationship between the number of hemlock juveniles present and the number of competitor juveniles present, we cannot assume that encroachment my competitor hardwoods is the cause of hemlock decline. In fact, it is more likely a combination of several of these variables.

Understanding exactly *what* combination of factors is becoming more and more critical as climatic envelopes continue to shift. At temperatures increase, the wooly hemlock adelgid will likely move into Upper Great lakes region. This invasive insect, which is lethal to adult hemlocks within 3-5 years, will create gaps in which intense competition for growth will occur. If hemlocks are not capable of regenerating sufficiently, encroachment by competitor species is almost certain. In order to protect the eastern hemlock and the high ecological value it holds, we must continue to study the factors which influence its survival, as well as quantify its capacity to maintain its place in the Northwoods landscape.

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Figures

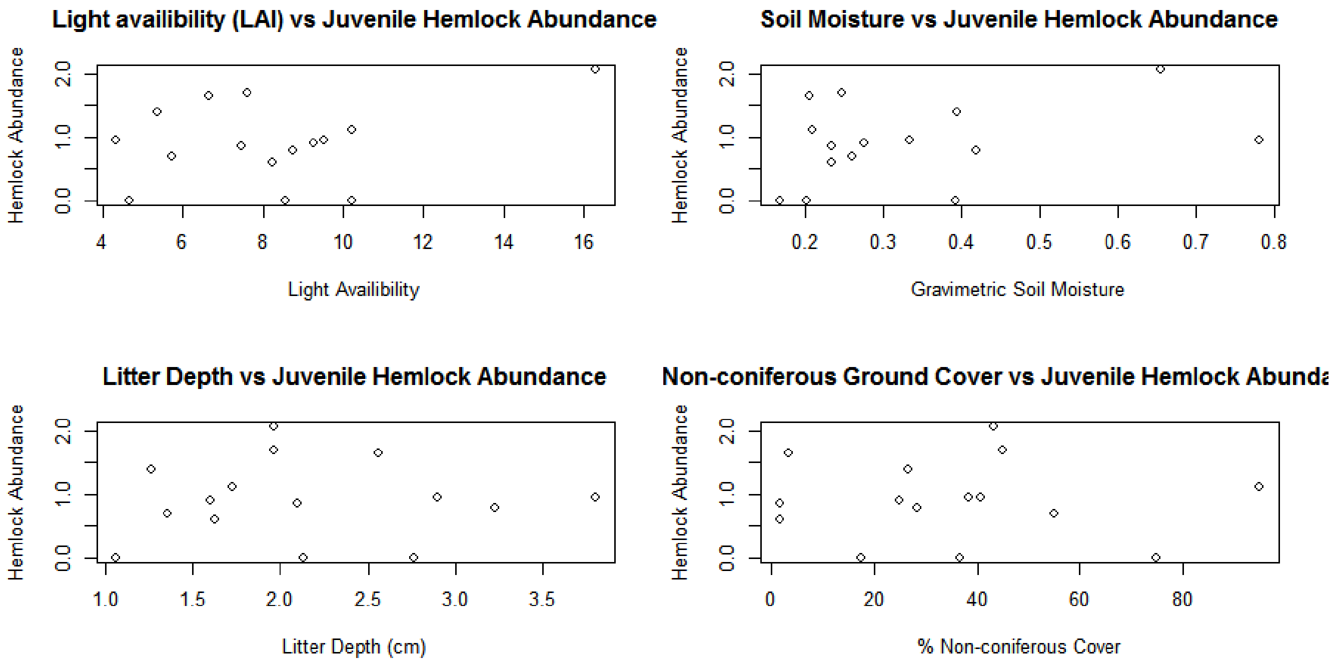

Figure 1: Abiotic Factors vs Juvenile Hemlock Abundance

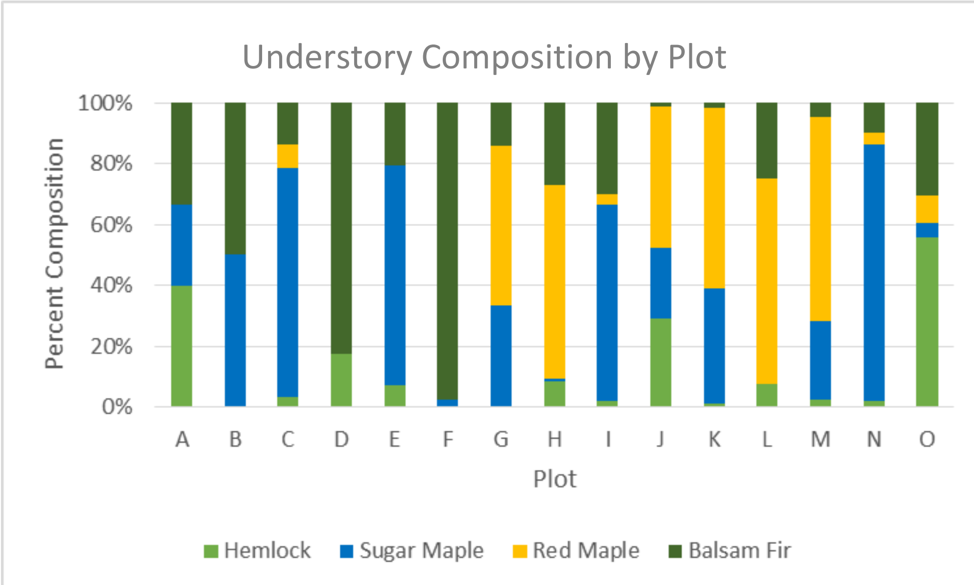

Figure 2: Tree species composition in the understory by plot

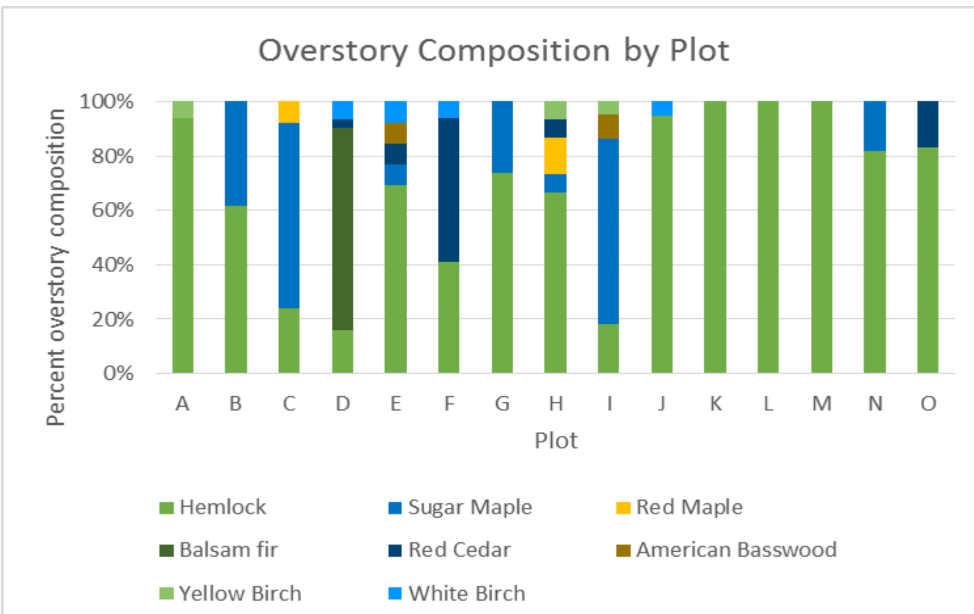

Figure 3: Tree species composition in the canopy by plot

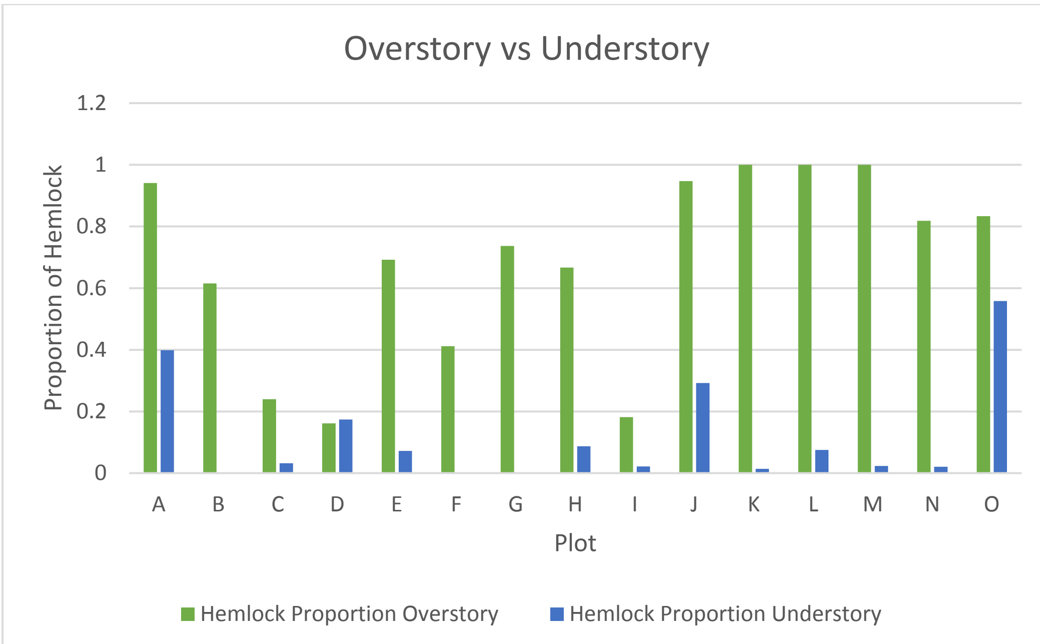

Figure 3: Proportion of Hemlocks in the understory vs the overstory. [n=15, p=.0001]